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Pilot Visual Acquisition of Traffic: Operational Communications From OpEval-1

O. Veronika Prinzo
Civil Aeromedical Institute
Federal Aviation Administration
Oklahoma City, Oklahoma 73125

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16. Abstract:

Avionics devices designed to provide pilots with graphically displayed traffic information will enable pilots to acquire and verify the identity of any intruder aircraft within the general area, either before or in accordance with a controller-issued traffic advisory or alert. A preliminary evaluation was performed of an airborne capability to display traffic information (OpEval-1, July 1999). As part of that evaluation, audiotapes were analyzed of the communications between pilots flying aircraft equipped with a cockpit display of traffic information (CDTI) and terminal radar approach controllers, who provided them with air traffic services. The results revealed that pilots and controllers participated more frequently in collaborative communications that resulted in a reduction in radio-frequency congestion and improved overall communications. Pilot persistence in scanning for traffic called by air traffic control (ATC) — especially when that traffic was readily visible on the CDTI display, but not out the window — may have led to more responsive traffic reports, increases in positive visual acquisitions, and consequently proportionally fewer pilot reports of "negative contact." Only 4% of the pilots' and controllers' messages revealed communication problems such as inaccuracies, procedural deviations, and non-routine transactions. Information load, the novelty of pilot-initiated traffic calls, access to and knowledge of the traffic call sign by pilots, as well as the variability in ATC message structure each contributed to the occurrence of communication problems. The voice tape analyses suggest that new procedures and operational communications will be needed to support CDTI and guidance in collaborative decision-making involving air-ground traffic flow management. Whenever any new system, technology, capability, or application is evaluated prior to implementation in a well-defined environment such as the National Airspace System, the importance of pilot and controller communication training to overcome the interference effects of past experiences with ATC communication will need to be included as part of a comprehensive plan towards implementation.

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Innovations in Pilot Visual Acquisition of Traffic: New Phraseology for Air Traffic Control Operational Communication

INTRODUCTION

Pilots and air traffic controllers operate as coordinated teams to ensure the safety of passengers and cargo. In flight, pilots scan the airspace for the presence of other aircraft to avoid. Meanwhile, air traffic controllers scan their radar displays to ensure separation between airborne aircraft according to prescribed minimums. "Unless an aircraft is operating within Class A airspace or omission is requested by the pilot, issue traffic advisories to all aircraft (IFR or VFR) on your frequency when, in your judgment, their proximity may diminish to less than the applicable separation minima. When no separation minima applies, such as for VFR aircraft outside of Class B/Class C airspace, or a TRSA, issue traffic advisories to those aircraft on your frequency when in your judgment their proximity warrants it"[1]. When issuing traffic advisories, controllers use standard phraseology contained in FAA Order *7110.65, Air Traffic Control.* For example the radio call, "Traffic, eleven o'clock, one zero miles, south bound converging, Boeing Seven Twenty Seven, one seven thousand" directs a pilot's visual scan to a limited viewing area of the sky. Upon detecting the aircraft, the pilot typically would inform the controller that the traffic is in sight. However, if the intruder goes undetected, the controller will issue instructions for a pilot response to resolve the threat. Aircraft flying at speeds in excess of 4 miles per minute[2] make receipt of timely replies from the pilots to controllers that much more compelling.

Avionics designed to provide pilots with graphically displayed traffic information are being developed to aid the visual acquisition process. The cockpit display of traffic information (CDTI) will present the visual depiction of the geometry of another aircraft in relation to the pilot's own aircraft. It would seem that having a CDTI would facilitate and direct the pilot's visual scan to a more precise location to detect the other aircraft — provided the other aircraft can transmit its location. Otherwise, the utility of the CDTI would be limited in use. These devices will enable pilots to acquire the aircraft and verify the identity of any intruder within the general area either before, or in accordance with, a controller-issued traffic advisory or alert. However, direct access to information involving the location and identity of other aircraft in the vicinity by pilots may necessitate the development of a new phraseology to accommodate operational communication and procedures.

A preliminary evaluation was performed of an airborne capability to display traffic information (OpEval-1, July 1999). Before proceeding any further, it must be pointed out that OpEval-1 provided an opportunity to demonstrate new air- and ground-based capabilities and systems at a FAA-controlled airport and en route facility. With that in mind, it is important to note that it was not possible to apply true experimental and control conditions, comparable to what would be expected when planning and executing laboratory-based experiments. In addition, since the amount of instruction and training that the pilot and controller participants received was not documented, it was impossible to exercise any statistical control on the data (e.g., treating the number of hours of training as a co-variant). Finally, since the demonstration was an operational evaluation of the CDTI during actual flights, much more communication data were obtained when CDTI was in use than not, which precluded a quantitative statistical analysis of the data. A final report of that evaluation was prepared by the Operational Evaluation Coordination Group (2000).

[1] FAA Order 7110.65M, TRAFFIC ADVISORIES Para 2-1-21. Air Traffic Control 7110.65M, is a FAA order that prescribes air traffic control procedures and phraseology for use by personnel providing air traffic control services. Controllers are required to be familiar with the provisions of this order that pertain to their operational responsibilities and to exercise their best judgment if they encounter situations not covered by it.

[2] 1 knot is equal to 1.15078030303 miles per hour.

As part of that evaluation, audiotaped recordings of communications were analyzed between pilots flying aircraft equipped with a CDTI device and terminal radar approach controllers who provided them with air traffic services. The objective of the voice tape analysis was to identify any change in visual acquisition time (VAT), flight identifier phraseology, or workload that resulted when pilots were flying with and without the benefit of CDTI. This report provides a general description of those findings.

METHOD

Participants

Sixteen pilots, serving as a captain or first officer, flew aircraft equipped with CDTI while three air traffic controllers provided air traffic control (ATC) services. The pilot participants were paid volunteers who received briefings and participated in training exercises prior to the evaluation. The controllers, who also were volunteers, were on a temporary detail during training and on regular schedule during the evaluation.

Procedure

Training on CDTI Phraseology. Prior to OpEval-1, pilots and controllers participated in several pre-OpEval-1 simulations that were conducted at the Integration and Interaction Laboratory (I-Lab) of the MITRE Corporation Center for Advanced System Development (CAASD). During these simulations, pilots received instruction on how to respond to ATC-issued traffic calls and listened to a combination of ATC and pseudo-pilot communications over a party line. Two weeks prior to OpEval-1, each pilot had received a set of flight-crew maneuver cards describing the CDTI and standard phraseology contained in *FAA Order 7110.65/Aeronautical Information Manual* (AIM) that they would use during OpEval-1. Furthermore, during the preflight briefing conducted the day of the evaluation, pilots were reminded to reply to ATC-issued traffic calls according to the standard or the CDTI Phraseology — depending on CDTI usage. As a further reminder, a set of the cards was prominently displayed onboard each participating aircraft.

Experimental Flight. As shown in Figure 1, each circuit, depicted with directional arrows, was flown by the pilots who followed a basic racetrack pattern of performing all right or left turns and missed approaches. A circuit consisted of an aircraft completing a full cycle around the traffic pattern that culminated in a missed approach or landing. Unfortunately, Instrument Meteorological Conditions (IMC) prevailed during the morning flights and precluded the extensive use of visual separation and

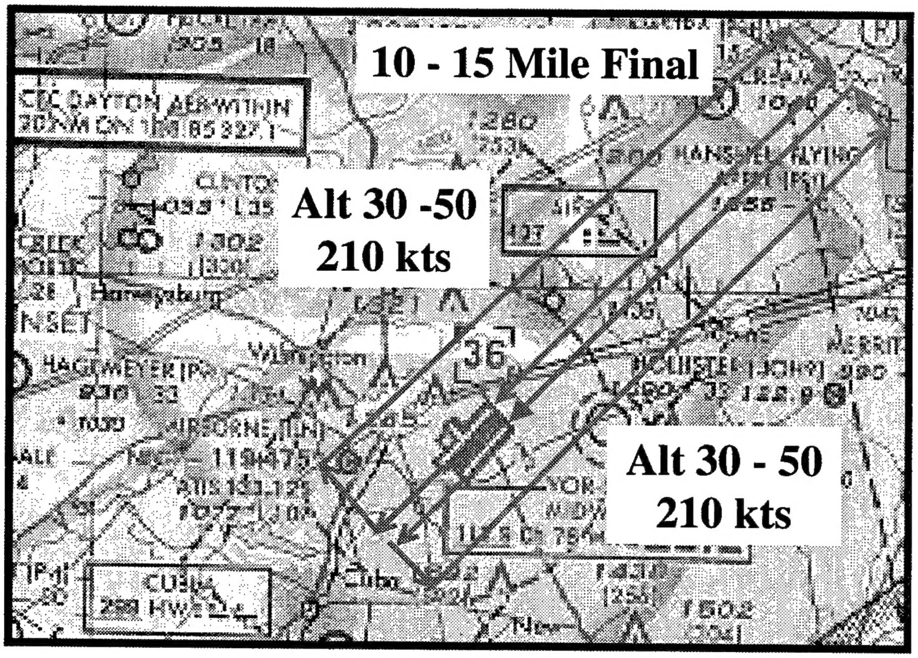

Figure 1. Depiction of the Circuits Flown by Participating Aircraft.

visual approaches. However, during the afternoon session, the weather conditions were more favorable: Visual Meteorological Conditions (VMC) allowed controllers to use visual separation and visual approaches. Consequently, the pilots flew between 6-15 circuits during the afternoon, receiving instructions over their headsets to vector their aircraft into a right- or left-hand pattern at altitudes specified by the controller.

Materials

The data consisted of 3 hours of audiotaped pilot/ATC communications provided by the participating Terminal Radar Approach Control (TRACON) facility. Each 1-hour tape was labeled with the name of the facility, date of recording, radio frequency sampled, time interval, and runway assignment. Specifically, Channel 1 contained the voice communications, and Channel 2 contained the local time stamped by the day, hour, minute, and whole second (s) according to the Universal Time Coordinated standards.

Data Extraction Procedure

Two copies of the audiotapes were made from each original to minimize stretching of the tape medium. The transcriber received one copy, and the other was used by the Subject Matter Expert (SME) who listened to the recordings while verifying the accuracy of the verbatim transcripts. Each message was subsequently encoded with its corresponding transmission start and end time. The original audiotapes local time stamps were translated by a Datum Time Code Generator/Translator and then converted into whole seconds. A continuous record of radio frequency use and nonuse was included with each transcript. Next, the SME parsed each message into message elements and labeled them by speech-act category (e.g., Instructions, Advisories) and aviation topic (e.g., traffic, heading, altitude, speed).

The audiotapes and transcripts aided the SME in the identification of air traffic (AT) communication sets. As shown in Figure 2, an AT communication set involved only those transmissions between an air traffic controller and the pilot of the aircraft receiving a traffic-related transmission.

Generally, an AT communication set began with the air traffic controller issuing a traffic advisory, as illustrated by transmission 1. Often pilots respond with "looking," followed by either "negative contact" or "traffic in sight," (or similar words), as was the case in message 6. A controller also could query the pilot to "report the traffic in sight." Alternatively, if no pilot response was forthcoming, the controller might restate the traffic advisory.

Dependent Measures

ATC Workload. Although various measures of ATC workload exist, for the purposes of the voice-tape analysis, it was defined as the number of active aircraft still on frequency when the controller initiated a transmission. An aircraft was counted as being under positive control when it was radar identified by the controller and the pilot established initial contact with the controller. An aircraft was no longer under positive control when the controller instructed the

		Time (in seconds)				
Speaker	Message	Start	End	Lapse	Acquired	Total
ATC	*1. CAA1 / TRAFFIC ONE O'CLOCK FIVE MILES ON FINAL THREE THOUSAND BOEING*	**783**	**788**	4	**39**	**48**
CAA2	2. CAA2	790	792	2	-	-
ATC	3. CAA2 / YES SIR	793	795	1	-	-
CAA2	4. AIRPORT IN SIGHT / CAA2	796	798	1		
ATC	5. CAA2 / CLEARED {TYPE} APPROACH	805	808	7		
CAA1	*6. WE HAVE THE BOEING CAA2 / CAA1*	**827**	**831**	19	-	-

Figure 2. An Example of an Air Traffic Communication Set.

pilot to contact the tower. Other indicators of workload included the amount of time on frequency (i.e., frequency occupancy time, FOT) and the amount of time the frequency was not in use (i.e., 'dead-air' or lapse time), as well as the total number of messages exchanged between a controller and the pilot of an aircraft during each circuit, as previously displayed in Figure 1.

Visual Acquisition Time (VAT). VAT was defined as the time lapsed, in whole seconds (s), from the end of the controller's first traffic-related transmission until the start of the pilot's reply indicating visual contact or negative contact with the aircraft (denoted as traffic by the controller). For example, the dashed arrow in Figure 2 illustrates the computation of VAT that began at 783s (message 1) and ended in visual acquisition at 827s (message 6) when the pilot of CAA1 informed ATC that the target traffic was acquired. In that example, VAT was completed in 39s.

Total AT Communication Set-Time. To determine the total AT communication set-time, a simple difference was computed between the start of a controller-initiated traffic advisory or report and the end of the pilot's final reply to that message. For instance, in Figure 2, the solid arrow indicates a transaction began at 783s and ended at 831s when the pilot of CAA1 completed the transaction. This resulted in a total AT set time of 48s. Notably, it might have been possible for the pilot to report spotting the traffic sooner, but the radio frequency was unavailable. To account for this possibility and to determine if the total AT set time was inflated, lapse time (or "dead air") was computed as the amount of silence between consecutive transmissions. As seen in Figure 2, the amount of silence varied from 1 - 19s.

Communication Workload. Communication workload has many facets and information load is but one attribute. Information load consists of both the amount and complexity of information present in a message. The amount of information in a message was determined by counting the number of message elements present in a transmission (Prinzo, Britton, & Hendrix, 1995). Complexity was determined by counting the number of digits, letter groups, or both, that indicated a direction or distance, aircraft call sign, an aircraft type, etc. (e.g., 12 o'clock, left, right, north, CAA123, Boeing 727) in a message element. These digits and letter groups were labeled as bits of information.

For example, the following transmission, "CAA***321*** / Following traffic **six** miles **ahead** CAA <u>123</u> / Cleared visual approach runway ***22*** **left** / Multiple aircraft off your **right** landing on the parallel / Contact Wilmington Tower" has an information load of 12 bits of information. It has 5 message elements consisting of (1) the receiving aircraft's call sign, (2) route/position advisory, (3) runway clearance, (4) traffic advisory and a (5) transfer of communications. Complexity consists of 7 bits, and they are presented in a bolded-italics font.

Flight ID Phraseology. Because the traffic flight identifier (TFID) is a deviation from the *FAA Order 7110.65/AIM*, its inclusion in ATC/pilot communications may have unknowingly changed the normal exchange of information. To evaluate the usage and

Table 1. Pilot Response to a Traffic Advisory and the Evaluation Rule

Source	Phraseology	Rule
7110.65/AIM	"traffic in sight" "negative contact"	A pilot response to a controller-issued traffic advisory with words other than "traffic in sight" or "negative contact" did not comply with the stated phraseology.
CDTI Phraseology CDTI In Use	"(Ownship call sign) (target TFID) in sight." "(Ownship call sign) roger, traffic not in sight."	A pilot response to a controller issued traffic advisory either did or did not comply with the stated phraseology.
CDTI Not In Use	"(Ownship call sign) traffic in sight." "(Ownship call sign) roger, traffic not in sight."	A pilot response to a controller issued traffic advisory either did or did not comply with the stated phraseology.

effect of the TFID on operational communication, the SME coded pilot responses to traffic calls according to *FAA Order 7110.65/AIM* and the CDTI Phraseology (Table 1). Initially, the rule to include "roger" was accepted; however, it was excluded when it became clear from the SME that pilots did not include it as part of their traffic reports. As a result, "roger" was excluded from the evaluation rule.

Communication Problems. Given the novelty of the traffic-flight identifier as a new message element in a traffic-related message, new communication problems may have emerged. Specifically, a communication problem "refers to any disturbance of routine communication, where controllers and pilots do not follow standard procedures, and/or where they must interrupt information transfer in order to clarify the communication" (Morrow, Lee, & Rodvold [1990] pp. 36). Communication problems include inaccuracies, procedural deviations, and non-routine transactions involving misunderstandings or other problems related to successful information transfer. Although communication problems often contribute to frequency congestion and workload, they do not necessarily lead to operational errors or incidents. Since the TFID is a new message element designed for pilot use during OpEval-1, it was evaluated to determine its influence, if any, on ATC/pilot communication.

In summary, message counts, contents, duration, rates, and reply latencies were the objectively derived measures of communication that were extracted from the time-stamped voice tapes. They were used to compute descriptive statistics that summarized CDTI use versus non-use on traffic awareness, workload, and the confirmation of visual traffic acquisition latencies between ATC and the participating flight crews[3]. They also provided some insights and implications for future air traffic operations and communication procedures.

RESULTS

ATC Workload

There were 67 circuits (20 CDTI Not In Use, 47 CDTI In Use) in which pilots and controllers exchanged 1127 messages containing air traffic (n=300) and other (n=827) information. Each complete circuit lasted between 160-590s (M=352.92s) when CDTI was in use and 132-562s (M=363.56s) when it was not. Of particular interest in OpEval-1 was the communication between the controllers and pilots during these circuits. Notably, as seen in Table 2, while controllers sent fewer messages per circuit when CDTI was in use, they also spent less time on average (per aircraft), conveying traffic-related information to the pilot. For the pilot, there also seemed to be a slight reduction in the number of air traffic-related messages when CDTI was in use, without an appreciable change in frequency occupancy time.

Visual Acquisition Time (VAT). Before examining VAT, it was important to determine if any differences in pilot reply times to traffic calls resulted from

Table 2. Mean and Standard Deviation (S.D.) of ATC/Pilot Messages and Frequency Occupancy Time (FOT) per Circuit Presented by Speaker, CDTI Usage, and Type of Message

	Messages per Circuit			Frequency Occupancy Time		
	Mean (S.D.)			Mean (S.D.)		
Source	Air Traffic	Other	Total	Air Traffic	Other	Total
Speaker by CDTI Usage						
ATC - Not In Use	3.1 (1.9)	6.0 (3.0)	8.7 (2.8)	17.7 (8.1)	17.5 (9.8)	33.5 (13.5)
ATC - In Use	2.6 (1.9)	5.6 (2.0)	7.8 (2.7)	14.3 (10.2)	16.8 (6.4)	29.3 (11.7)
Pilot - Not In Use	2.6 (1.6)	6.4 (2.7)	8.7 (2.8)	5.4 (3.5)	13.4 (5.8)	18.3 (7.0)
Pilot - In Use	2.1 (1.3)	6.5 (1.8)	8.4 (2.3)	5.5 (3.5)	13.6 (4.4)	18.5 (5.2)

[3] Since the conditions necessary to perform inferential techniques were not met, any statistically significant effects that may have resulted from CDTI use or non-use could not be inferred from the data (Kerlinger, 1986).

frequency non-availability. To do this, the percentages of silence and mean lapse time between successive transmissions (i.e., the average duration of silence) was computed for all transmissions. The findings presented in Table 3 revealed that for all of the message transmitted by pilots when CDTI was in use, 87% were preceded by 0-3s of silence compared with 93% when CDTI was not in use. The overall increase in mean silence when CDTI was in use suggested that the radio frequency was available to pilots for reporting to ATC and it was concluded that it would not have artificially inflated the VAT.

To be considered as a part of the database from which visual acquisition times would be examined, AT communication sets must have originated with the controller and not the pilot. Furthermore, because controller-updated traffic calls could produce multiple pilot responses, VAT was measured from the end of the controller's first issuance of an ATC message with traffic-related content to the start of the pilot's reply indicating "positive" or "negative contact," or "looking" as an outcome.

A preliminary examination of the data resulted in the removal of 3 of the 84 AT communication sets because they contained delays greater than 180s; all of the other sets were less than or equal to 68s. The data were also excluded because they would have artificially inflated the mean VATs and total time to complete an AT communication set. Presented below are the controller messages to each of the aircraft involved in these long delays. The pilots may have been busy setting up for the approach, the traffic was too far away to spot, or the delays may have resulted for other reasons.

"... TURN RIGHT HEADING TWO ZERO ZERO JOIN THE TWO TWO RIGHT LOCALIZER THE AIRPORT IS TWO O'CLOCK ONE FIVE MILES THE TRAFFIC TO FOLLOW IS THREE O'CLOCK AND FIVE MILES ADDITIONAL TRAFFIC OPPOSITE BASE LANDING ON THE PARALLEL A DC NINE."

"... TRAFFIC TEN O'CLOCK EIGHT MILES NORTHEAST BOUND ON THE DOWNWIND THIRTY SIX HUNDRED A BOEING CONTACT WILMINGTON TOWER YOUR SPEED AND SPACING IS FINE."

"... FOLLOWING TRAFFIC SIX MILES AHEAD CLEARED VISUAL APPROACH RUNWAY TWO TWO LEFT MULTIPLE AIRCRAFT OFF YOUR RIGHT LANDING ON THE PARALLEL CONTACT WILMINGTON TOWER."

When the remaining data were examined, 76% of the 54 AT communication sets that occurred while CDTI was in use involved pilot reports of "traffic in sight." However, as the data in Table 4 show, when CDTI was not in use, positive reports decreased to 63%. In addition to an increase in CDTI-based visual acquisitions, another benefit resulting from CDTI was that pilots reported traffic faster. The longer mean VATs suggest that, when traffic was not immediately visible out-the-window, CDTI may have encouraged pilots to continue scanning for traffic called by ATC — especially when that traffic was readily visible on their displays. The presence of CDTI on the flight deck may have encouraged the pilots to keep looking and, thus, contributed to the 13% increase in positive sighting reports.

Total AT Communication-Set Time. Total AT communication-set time was measured in whole seconds from the start of the controller's first issuance of a traffic-related message until the end of the pilot's final reply conveying "positive" or "negative" contact or "looking." The data in Table 5 show that when CDTI was not in use, proportionally fewer of the pilots' positive sightings were completed in 15s or less. At 60s, 58% of the positive sightings were completed when CDTI not in use and 66% when it was not.

Measures of Communication Workload. A second set of analyses, performed on the entire 1,127 messages and presented in Table 6, revealed that 30.5% of the messages not considered to be complex involved 1.6% of the communication problems (left panel). As indicated by the column in that table labeled "Messages with Communication Problems," pilots and controllers did exceptionally well communicating with one another — especially since only 3.7% of all their messages contained communication problems. As shown in the right-hand panel of Table 6, when complexity was combined with the amount of information in a message to provide an index of information load, the data revealed that 79% of the messages with an information load of 6 or less involved 2.9% of the communication problems. In addition, a majority of the messages had a moderate information load of 5-6. Of the 42 messages that had communication problems, the majority had information loads ranging from three to six and rarely were problems found in messages with a light information load of 1-2.

Table 3. Percentage and Mean Lapse Time Between Successive Transmissions (in seconds) Presented by Message Contents and CDTI Usage (Pilot-Initiated Messages Only)

	Amount of Silence Preceding a Pilot Message										
Source	0-1s	2-3s	4-5s	6-15s	16-30s	31-45s	46-60s	>60s	Total	Mean (SD)	N
Message Type by CDTI											
AT - Not In Use	16%	9%	1%	1%	0%	0%	0%	0%	26%	1.7 (2.2)	46
AT - In Use	13%	7%	2%	1%	0%	0%	0%	0%	22%	1.7 (1.4)	90
Other - Not In Use	53%	14%	1%	2%	2%	0%	0%	0%	74%	2.0 (3.6)	128
Other - In Use	56%	11%	2%	4%	3%	1%	1%	1%	78%	3.5 (8.6)	313
All Messages - Not In Use	70%	23%	2%	3%	2%	0%	0%	0%	100%	1.9 (3.3)	174
All Messages - In Use	69%	18%	4%	4%	3%	1%	1%	1%	100%	3.1 (7.6)	403

Table 4. Frequency of AT Communication Sets Presented by VAT, Outcome and CDTI Usage

	Pilot Visual Acquisition Time										
Source	0-1s	2-3s	4-5s	6-15s	16-30s	31-45s	46-60s	61-68s	Total	Mean (SD)	N
Outcome by CDTI Usage											
Positive - Not In Use	26%	18%	4%	4%	4%	4%	4%	-	63%	8.6 (15.9)	17
Positive - In Use	39%	15%	2%	4%	4%	7%	2%	4%	76%	10.6 (18.2)	41
Negative - Not In Use	18%	15%	-	4%	-	-	-	-	37%	2.3 (3.1)	10
Negative- In Use	2%	11%	6%	2%	-	4%	-	-	24%	9.2 (14.5)	13

Table 5. Total Time to Complete an AT Set (in seconds) Presented by Outcome and CDTI Usage

	Total Time on Frequency Per AT Communication Set									
Source	6-10s	11-15s	16-30s	31-45s	46-60s	61-75s	75-274s	Total	Mean(SD)	N
Outcome by CDTI Usage										
Positive - Not In Use	22%	22%	7%	7%	-	4%	-	63%	17.6 (16.4)	17
Positive - In Use	28%	22%	7%	4%	7%	4%	4%	76%	28.1 (46.3)	41
Negative - Not In Use	7%	18%	-	-	7%	4%	-	37%	25.3 (23.6)	10
Negative - In Use	-	13%	-	-	4%	6%	2%	24%	48.0 (54.5)	13

Table 6. Percentages and Number of All Messages and Only Messages with Communication Problems Presented at Each Complexity and Information Load Index

Index	Complexity				Information Load			
	All Messages		Messages with Communication Problems		All Messages		Messages with Communication Problems	
	%	n	%	n	%	n	%	n
0	30.5%	344	1.6%	18	.1%	1	-	-
1-2	54.4%	613	1.4%	16	8.8%	99	.1%	1
3-4	12.2%	138	.7%	8	32.9%	371	1.8%	20
5-6	2.4%	27	-	-	37.4%	422	1.1%	12
7-8	4.0%	5	-	-	14.7%	166	.4%	5
9+	-	-	-	-	6.0%	68	.4%	4
Total	100.0%	1,127	3.7%	42	100.0%	1127	3.7%	42

Table 7. Communications Workload Presented by Speaker and CDTI Usage

Source	Amount of Information Mean (SD)	Message Complexity Mean (SD)	Information Load Mean (SD)	Number of Messages n
Speaker by CDTI Usage				
ATC - Not in Use	2.95 (1.2)	3.80 (1.8)	6.75 (2.6)	55
ATC - In Use	2.77 (1.2)	3.73 (2.3)	6.50 (3.0)	109
Pilot - Not in Use	2.41 (.9)	1.33 (.9)	3.74 (1.4)	46
Pilot - In Use	2.44 (.9)	1.52 (1.0)	3.97 (1.6)	90

A more comprehensive analysis of communication workload was performed separately for the 300 pilot and controller messages involving only traffic information. As part of that analysis, communication problems were again identified and categorized according to speaker, CDTI usage, and information load. The results (Table 7) show that the pilots' traffic-related messages generally were more complex and contained slightly more information when CDTI was in use, compared with when it was not in use. Based on the data, pilot messages had a greater overall information load for controllers to process. Interestingly, the opposite pattern emerged for controller communication. That is, when pilots were flying CDTI approaches, the controllers tended to send less information per message, and their messages also were less complex. It would seem that the messages that were transmitted when CDTI was in use had a smaller information load for pilots to process. This reversal is not surprising since CDTI provides pilots with an increased opportunity to actively share relevant traffic information with controllers.

As with the analysis of the entire data set, those associated with the 300 air traffic messages were not without problems. In fact, like the overall data, roughly 4% involved one or more communication problem. For pilots, communication problems involved a request for ATC to repeat a traffic position report, a readback error, an incorrect call sign usage, and call sign confusions. Generally, as shown in

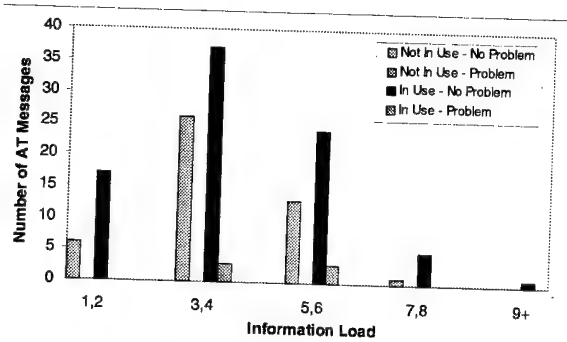

Figure 3a. Pilot Air Traffic Messages Presented by Information Load.

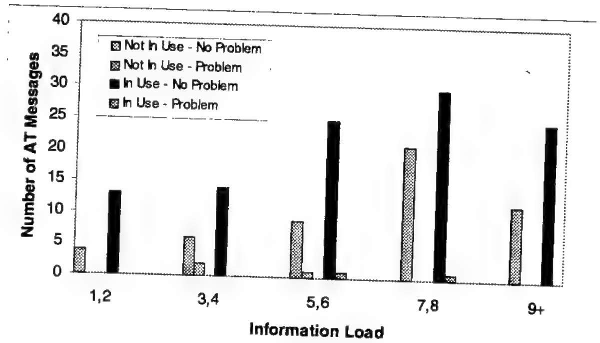

Figure 3b. Controller Air Traffic Messages Presented by Information Load.

Figure 3a, pilot AT messages with communication problems had information loads of 3, 4, or greater, and all of them occurred when CDTI was in use.

As shown in Figure 3b, unlike the pilots, 2 of the controllers' AT messages with communication problems occurred when CDTI was in use and 3 occurred when not. For controllers, as with pilot-AT messages, communication problems occurred in AT messages with information loads of 3, 4, or greater. Some specific examples of communication problems that were encountered during the OpEval-1 involved the delivery of traffic advisories to the pilot of the wrong aircraft, calling aircraft by the wrong flight identifiers, misunderstandings, and providing clarification to pilots.

Flight ID Phraseology. Flight ID phraseology was evaluated by comparing the content of the pilot's reply to a traffic call with standards contained in *FAA Order 7110.65/AIM* and the CDTI Phraseology. Of the 134 pilot-generated replies, 68 resulted in positive contact (51%), 16 in negative contact (12%), and 28 ended with looking (21%) as a final outcome. An additional 7 were updates to previous traffic advisories (5%), 10 closed the transaction (8%) and 5 were not relevant to the traffic situation (4%).

In spite of the pre-OpEval training, briefings, and memory aides, only 36.6% of their traffic reports complied with *FAA Order 7110.65/AIM* standards and only 14.4% were in agreement with the CDTI phraseology (e.g., "{OWNSHIP} {TARGET TFID} in sight,") (see Figure 4). In fact, the only time that the phraseology for CDTI and FAA Order 7110.65/AIM was in agreement was when CDTI was not in use, and the pilot reported the traffic in sight. Thus, more often than not, pilots' previous communication practices took precedence over the phraseology developed for the operational evaluation. Consequently, 45% of the pilot responses did not comply with either phraseology. Some examples of non-standard phraseology include, "This is {Ownship} well, we got him sir" and "{Ownship} ... will call either the traffic or the field."

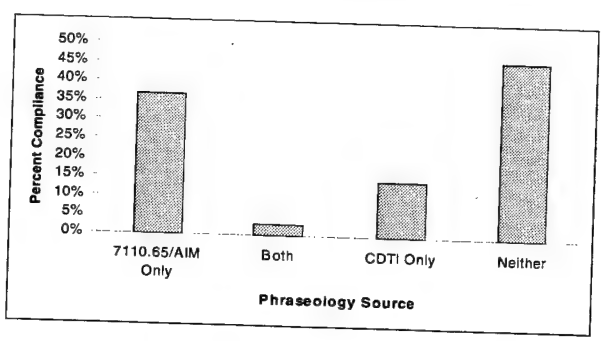

Figure 4. Pilot Compliance with CDTI and 7110.65/AIM Phraseology during OpEval-1.

Pilot responses to ATC traffic calls were subsequently categorized according to the types of traffic identifiers presented in Table 8. Some representative examples of each type of traffic identifier are presented for clarity.

As shown by the data in Table 9, when positive outcomes were considered, 58% of pilot replies that occurred while CDTI was in use included the full or partial call sign of the traffic aircraft, compared with 12% when CDTI was not in use. As shown under the column labeled "Generic," 75% of positive sightings, regardless of CDTI usage, failed to provide the controller with information ensuring that the designated traffic was acquired (19% with CDTI and 56% without CDTI). For non-acquired traffic, again regardless of CDTI availability, approximately 37% of the pilot replies only provided a generic referent to the aircraft previously identified by ATC in the traffic call (20% CDTI not in use and 17% CDTI in use).

Table 8. Examples of the Type of Traffic Identifiers Included in Pilot Relies to ATC Traffic Calls

Traffic Flight Identifier	Pilot Responses to ATC Traffic Calls
Full call sign:	... HAS CAA ONE TWENTY THREE
Partial call sign:	... WE GOT THE CAA — or I HAVE THE ONE TWENTY THREE
Aircraft type:	... WE HAVE THAT BOEING TRAFFIC IN SIGHT
VFR:	... THE VFR IS NOT IN SIGHT
Generic:	... NEGATIVE CONTACT ON THE SECOND TRAFFIC

Table 9. Pilot Traffic Replies (n=84) Presented by Traffic Flight Identifier and CDTI Usage

	Types of Traffic Flight Identifiers Included in Response to ATC Traffic Calls				
Source	Full Call Sign	Partial Call Sign	Aircraft Type	VFR Traffic	Generic
Outcome by CDTI Usage					
Positive - Not In Use	4%	8%	12%	-	56%
Positive - In Use	46%	12%	5%	-	19%
Negative - Not in Use	-	-	-	-	20%
Negative - In Use	-	-	-	2%	17%

Table 10. Location of Pilot's Ownship Call sign and TFID Presented by CDTI Usage

	CDTI Usage							
Source	Not In Use				In Use			
Identifier	First	Last	Embedded	Missing	First	Last	Embedded	Missing
Ownship	7	5	1	5	21	9	6	18
Traffic	-	1	-	-	3	5	18	-

As previously mentioned, although a reference list of pilot phraseology was constructed, taught, briefed, and displayed on the flight deck, pilot use of that phraseology and the form of their responses were highly variable and often reflected previous communication practices. The data presented in Table 10 certainly reflect that variability. Some examples using Ownship call sign (SID) and Traffic Flight IDentifier (TFID) included: (1) Okay we have uh [TFID] in sight [SID], (2) Ah we have the traffic in sight uh [TFID] confirm that, (3) [numbers] on the heading have the airport in sight and the traffic is [TFID], for [SID] has the airport in sight — we also have [TFID] in sight, and (4) [SID] has [TFID] [SID] has [partial TFID] in sight.

Communication Problems. Of the 10 detected AT communication problems, 3 are presented in Table 11, and their possible explanations are presented in Table 12. Problem #8 is a request from the controller for the pilot to repeat the transmission. It would seem that the controller was not prepared to receive a pilot-initiated traffic report. Problems #9 and #10 each stem from an unsolicited traffic report by the pilot of CAA124.

In problem #9 (Table 11), the controller misinterpreted "in sight" as the pilot of CAA1 - 11 reported the airport in sight. Hearing the phrase "in sight" often prompts controllers to hand-off the aircraft to the tower. Since the pilot had not previously closed that transaction with an acknowledgment, upon

Table 11. Examples of AT Communication Sets with Communication Problems

PROBLEM	SPEAKER	Examples of Three Communication Problems and Their Resolutions
	CAA111	**Departure / CAA uh 1 - 11 has CAA 1 - 23 in sight**
8	**ATC**	**I'm sorry uh / say that again**
	CAA111	**CAA 1 - 11 / has CAA 1 - 23 in sight**
	ATC	**CAA 1 - 11 / that works good for me /** cleared {type} approach {rwy} / follow the CAA 1 - 23 Boeing
	CAA111	Okay / here we go
	ATC	**CAA 1 - 11 / contact {name} Tower**
	CAA144	CAA 44 / heading 0 - 4 - 0
	CAA987	{name} Departure / CAA 9 - 87 / is with you passing 22 hundred ...
	ATC	CAA 9 - 87 / {name} Departure / radar contact / you can expect ...
9, 10	**CAA124**	CAA 1 - 24 / has **CAA 1 - 11 in sight**
	ATC	**CAA 1 - 11 / I'm sorry I thought we did that / contact {name} Tower**
	CAA124	**No / that was CAA 1 - 24 that has CAA 1 - 11 in sight**
	ATC	**CAA 1 - 24 / roger /** I'm going to extend ...

hearing "in sight," the controller may have thought it was still open. Becoming partially confused, the controller thought he had completed the hand-off and again instructed the pilot to contact tower. Problem #10 also results from the same unsolicited traffic report. When the pilot initiated the traffic call, the controller apparently processed only the second half of the message and thought CAA1 - 11 was the speaker. The communication problem was recognized only after CAA124 explained what transpired in the previous transmission and then the events that led to the communication problem were understood and resolved.

As shown in Table 12, resolution techniques varied with the type of AT communication problem in the transaction. The number of messages needed to resolve the problem varied with the complexity of the AT communication set. Some possible causal or contributing factors revealed that 70% of the communication problems involved TFIDs, of which 30% resulted in some type of confusion stemming from the pilots' knowledge of the TFID either through the CDTI, voice radio, or both.

DISCUSSION

As airspace congestion increases, controllers and pilots will continue to share precise and detailed traffic information to ensure safety. To accommodate this process, new technologies such as CDTI are being introduced to aid pilots in the detection, and visual acquisition of other aircraft. As these technologies are certified and made operational, the roles and responsibilities of pilots and controllers who use them will inevitably change. Some of these changes were demonstrated during the operational evaluation of CDTI.

For instance, the presence of CDTI onboard the aircraft seemed to create an apparent trade-off in air-ground workload. That is, when CDTI was in use, controllers sent fewer messages and spent less time conveying traffic-related information to pilots, while pilots sent fewer traffic-related messages to ATC. The very slight increase in the time pilots spent on frequency may be attributed, in part, to the traffic flight identifier being included in their traffic reports.

Table 12. Types of AT Communication Problems Presented by Resolution Technique and Outcome

Communication Problem	Resolution Technique	Outcome
Uncertainty of the identity of traffic	TFID used to verify/confirm traffic	Pilot visually acquires the designated traffic
Aircraft Type confused with Flight ID	ATC restates traffic location	Conflict resolved by a correction in the flight path
TFID used as Receiver ID	None	Uncorrected
TFID reported as Ownship	None	Uncorrected
TFID given as referent for target traffic position results in all or some of the message not understood or received	Pilot requests a repetition of the target traffic position	Traffic was not acquired
Pilot requests clarification of who the recipient was of the last transmission	Controller restates previous message	Recipient understood to be the pilot making the request
ATC request for confirmation that the pilot reported a positive visual acquisition of traffic	Pilot restates negative sighting report	Mutual understanding that the traffic was not acquired
Unsolicited traffic sighting results in all or some of the message not understood or received	Pilot retransmits per ATC request	Mutual understanding that traffic was acquired
Unsolicited traffic sighting results in ATC misidentifying TFID as the speaker of the previous transmission	None	ATC reissues a transfer of communication
Unsolicited traffic sighting results in ATC misidentifying TFID as the speaker of the previous transmission	Speaker identifies self and traffic	Mutual understanding of the identities of speaker and traffic

In contrast, the introduction of graphically displayed traffic information in the flight deck allows pilots to assume a more active role in traffic management. Together, pilots and controllers participated in collaborative communications. This was demonstrated by pilot-initiated traffic calls during OpEval-1. When the CDTI was in use, pilots detected nearby aircraft and occasionally provided ATC with unsolicited traffic sightings. In response, controllers either instructed the pilot to follow that aircraft for the approach (in lieu of issuing a traffic advisory or request a report the traffic in sight) or requested the pilot to repeat the transmission. Accordingly, when the opportunity to access the radio frequency became greater, as demonstrated by an increase in dead-air time, their communication became more effective. Consequently, CDTI can be a double-edged sword — when the novelty of pilot-initiated traffic calls wears off, there is a positive affect on the pilot-controller collaboration process. However, it also increases communication when ATC is either not prepared or does not expect a call from the pilot.

Other benefits of CDTI included more responsive traffic reports from pilots and increases in positive visual acquisitions. As mentioned previously, pilots did not always respond faster to controller-issued traffic advisories — in fact, at times they were slower. Pilots may have been encouraged to continue scanning for traffic called by ATC — especially when that traffic was readily visible on their CDTI displays but not out the window. This increased vigilance may have contributed to more sighting reports that were positive and proportionally fewer pilot reports of "negative contact."

In addition to pilots using the radio frequency less often, their messages also became more complex and had a greater information load when CDTI was in use. Interestingly, the opposite pattern emerged for

controller communications. When pilots were flying CDTI approaches, the controllers' messages tended to be less complex and had a smaller information load. This reversal is not surprising since CDTI affords pilots with an increased opportunity to participate more actively with ATC in traffic-awareness.

Clearly, pilots and controllers communicated accurately, as only 4% of the messages contained communications problems. Communication problems did not lead to operational errors or incidents; however, on occasion, they did contribute to frequency congestion and increased workload as resolution techniques were applied. The communication problems reported here included inaccuracies, procedural deviations, and non-routine transactions. If the controllers repeated all or part of their initial transmissions, this was not counted as a communication problem unless they provided clarification, resolved a misunderstanding, or corrected misinformation. The application of this definition of a communication problem was more conservative than that used by Cardosi (1993a), who analyzed tapes of pilot/controller communications from 3 Air Route Traffic Control Centers. In that report, 12% of the 508 transmissions contained communication problems that involved maneuvers for traffic avoidance, turns not for traffic, and traffic advisories. The difference in the number of communication problems involved controllers repeating some or all of their initial transmissions — in some cases pilots failed to reply, whereas in others, they missed or read back incorrectly the controllers' messages. For the OpEval-1 data, if a pilot failed to reply to the initial message and the controller did not query the pilot, it was not included as a communication problem.

While the overall number of communication problems was relatively low, many factors contributed to their occurrence. Some of the prominent factors included information load, the novelty of pilot-initiated traffic calls, access to and knowledge of traffic flight identifiers by pilots, as well as the variability in ATC message structure. Perhaps most important: All of the pilots' traffic-based communication problems occurred when CDTI was in use. Generally, pilots' messages with an information load of 3, 4, or greater were more likely to involve communication problems, as were controllers'. This finding is consistent with a similar pattern reported for message length (Morrow, 1996) in the TRACON environment and message complexity for en route communications (Cardosi, 1993b).

Given the novelty of pilot-initiated traffic calls, that controllers asked them to repeat unsolicited traffic reports is not at all surprising. Pilots typically do not initiate traffic calls but rather, receive them. Thus, controllers' requests for pilots to repeat their last messages increased controller communication workload and frequency congestion since 2 additional messages were exchanged — the "say again" and the unsolicited traffic report. In addition to using "say again" as a resolution technique, others included restatements, clarifications, and embellishments. All the techniques seemed to vary with the type of communication problem. The number of messages exchanged to resolve the problem depended partially on the complexity of the AT communication set.

A closer examination of these communication problems revealed that most of the communication problems involved traffic flight identifiers. It remains unclear whether the unique or combined effects of message structure (i.e., syntax) or the knowledge/presence of 2 different aircraft call signs in the same message (i.e., Ownship and traffic flight identifier), led to confusion and resulted in a communication problem. Recall that the participating pilots received practice on the CDTI phraseology, the syntax to use when reporting traffic, and they had access to phraseology reference list onboard their aircraft. Nevertheless, their responses were highly variable, generally reflecting their previous communication practices.

As the data show, the locations of Ownship call sign and the traffic call sign in a message were unpredictable and could have caused problems in comprehension and understanding. As Anderson (1990) pointed out, when the phrase structure of a message is unpredictable or ambiguous, the listener (reader) has a difficult time ascribing the intended meaning of the speaker (author). Consequently, comprehension suffers and misunderstandings arise. For example, the sentence, "They are cooking apples." The word "cooking" can be assigned either to the verb class (they are doing something — the something they are doing is cooking) or as an adjective that modifies the noun apple (the type of apple — a cooking apple). Therefore, the meaning of the sentence is derived from how it is parsed (i.e., its syntax).

Just as the sentence, "They are cooking apples" is syntactically ambiguous to the person trying to comprehend it, so was "CAA1 - 11 in sight" for the controller (see problems #9 and #10). The sentence

can be interpreted as CAA1-11 reporting to ATC that the airport is in sight and is waiting for an approach clearance. Alternatively, the pilot of an aircraft has informed ATC that CAA1-11 has been visually acquired as traffic. The ambiguity stemming from "CAA1 - 11 in sight" is whether to assign "CAA1 - 11" as the subject noun or the object of the message.

Unpredictable and ambiguous messages can create communication problems for the reader (listener). In each case, the reader (listener) must parse the message elements correctly before the author's intended meaning can be inferred. This example underscores the importance of a highly predictable message structure for ATC messages. When the presence of a syntactic, lexical, or semantic ambiguity arises from unpredictable message structures, they pose the threat of communication problems for the receiver of those messages. It is well known that the opportunities for miscommunications between pilots and ATC are ever present, existing mainly from the sheer volume of communication that occur daily. Fortunately, most miscommunications are detected, resolved, and are nothing more than minor nuisances — adding slightly to the communication workload. On the other hand, those that go undetected have the potential to lead to more serious and potentially dangerous events.

This finding actually highlights an issue related to introducing any new system, technology, capability, application, procedure, or phraseology into an existing, and well-defined environment such as the National Airspace System. First, it suggests the importance of pilot and controller communication training to overcome interfering effects of past experiences with ATC communication. This finding also suggests that the introduction of any procedural change to support CDTI may demonstrate similar initial interference effects for pilots and controllers, since they are highly skilled at using the existing, repetitive procedures to perform their respective duties.

The inclusion of a traffic flight identifier in a traffic advisory was a deviation from *FAA Order 7110.65/AIM*. Its presence in the message added an unknown factor into the normal exchange of traffic; its inclusion is not a normal way of issuing traffic. Therefore, before *FAA Order 7110.65* is modified, it would be beneficial to determine whether the same types of confusion would have occurred if the current procedures and phraseology for traffic advisory services had been included. Until such a test is performed, the continued use of the traffic flight identifier as part of traffic-related messages will continue to be a confusing factor.

The voice-tape analyses suggest that modifications to the existing procedures and operational communications may be needed to support CDTI. Clearly, operational procedures for conveying unique traffic information (such as the inclusion of the traffic flight identifier) could prove worthwhile as a means of minimizing communication problems, workload, and frequency congestion. As an example, consider the development of new ATC procedures that will be associated with ADS-B and CDTI. It would seem that, as part of that effort, there also should be a clearly defined phraseology with a standard message structure to minimize ambiguities — especially if two different aircraft flight identifiers are included in the same transmission.

In addition, and in support of the pilots who will use CDTI, it would seem prudent to develop standard operating procedures and practices that would include a phraseology that is both easy to learn and use. Both might prove beneficial for pilots when CDTI is operational. When pilots and controllers are provided adequate training and practice in applying these procedures and supporting phraseology, there should be a reduction in miscommunications resulting from confusions arising from message-structure ambiguities such as the ones that occurred during OpEval-1. Once developed, such a standard, when used faithfully, could ensure that only the intended recipient of the message replied to that message. In conjunction with the new technologies, these procedures will improve safety, enhance efficiency, and reduce the potential of human error associated with ATC/pilot communication.

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